

METHOD, DEVICE AND SYSTEM FOR EXCHANGING DATA VIA A BUS
SYSTEM

Background Information

The invention relates to a method and a device and also a
system for exchanging data such as in messages between at
5 least two stations connected via a bus system, according
to the independent claims.

The networking of control units, sensors and actuators
using a communications system or a bus system has
10 increased dramatically in recent years not only in modern
motor vehicle manufacturing and in engineering,
especially in the machine tool sector, and in automation
technology and other industrial applications, but also in
the private sector, for example in bus systems for
15 domestic buildings. It is possible in these cases to
obtain synergetic effects by distributing functions among
several control units. The term distributed systems is
used for this. Communication between various stations of
such a system is increasingly taking place via at least
20 one bus or at least one bus system. The communications
traffic on the bus system, access and receiving
mechanisms, and error handling are governed by a
protocol.

25 A protocol that is established in the automotive sector
and which is also being used to an increasingly greater
extent in other applications is CAN (Controller Area
Network). This is an event-triggered protocol, that is to

say, protocol activities such as transmission of a message are initiated by events that originate outside the communications system. Unique access to the communications system or bus system is resolved by
5 priority-based bit arbitration. A pre-requisite for this is that each message be assigned a priority. The CAN protocol is very flexible; it is therefore possible for further nodes and messages to be added without any difficulty as long as there are still free priorities
10 (message identifiers) available. The collection of all of the messages to be transmitted in the network, including priorities and their transmitting nodes, and possibly receiving nodes, are stored in a list known as the communication matrix.

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An alternative approach to event-triggered, spontaneous communication is the purely time-triggered approach. All communication activities on the bus are in that case strictly periodic. Protocol activities such as the
20 transmission of a message are triggered only by the passage of a time applicable to the entire bus system. Access to the medium is based on the allocation of time ranges in which a transmitting station has an exclusive transmission right. The protocol is comparatively
25 inflexible, and adding new nodes is possible only if the corresponding time ranges were left free beforehand. This circumstance forces the order of the messages to be set before operation is started. At the same time, the positioning of the messages within the transmission
30 periods must also be synchronized with the applications producing the contents of the messages so that the latencies between the application and the instant of transmission are kept to a minimum; otherwise, that is to say, if that synchronization is not performed, the

advantage of time-triggered transmission - minimal latency jitters when the message is being sent over the bus - would be destroyed.

5 The approach using time-triggered CAN, the so-called TTCAN (Time Triggered Controller Area Network), which is presented in German Published Patent Applications Nos. 100 00 302, 100 00 303, 100 00 304 and 100 00 305, and in ISO Standard 11898-4 satisfies the requirements outlined
10 above for time-triggered communication and satisfies the requirements for a certain degree of flexibility. The TTCAN fulfills those requirements by structuring the communication round (basic cycle) into so-called exclusive time windows for periodic messages of specific
15 communications stations, and into so-called arbitrating time windows for spontaneous messages of a plurality of communications stations. The TTCAN is essentially based on time-triggered, periodic communication which is clocked by a station or node giving the main time, the
20 so-called time master or timer, using a time reference message or short reference message. The period to the next reference message is referred to as the basic cycle and is subdivided into a specifiable number of time windows. A distinction is made between the local times,
25 or the local timers, of the individual stations and the time of the timer giving the global time. Further fundamental principles and definitions relating to the TTCAN will be explained hereinafter or may be learned from ISO 11898-4 and the related art mentioned.

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In the case of TTCAN bus communication, communication objects, that is to say, especially messages, that are defective and that are marked and made invalid by an error frame are not repeated so as to avoid any risk of

exceeding the time window or the cycle time by repeating the message and thereby impeding the message that follows. The receiving communication object for that destroyed message continues not to be updated until a message is received without error in an associated time window. In contrast to this, a defective reference message identified by an error frame is repeated, since it is not possible to do without that reference message. That repetition of the message results in the basic cycle affected being extended by the time from the beginning of the first defective reference message to the beginning of the reference message transmitted without error. Each of those errors leads to a further delay in the timing, with the result that those delays add up to a greater and greater deviation from the nominal time. Such a fault, for example a reference message transmitted with errors, accordingly leads to a time change or deviation from the nominal settings in the system. If two or more TTCAN buses or bus systems are in synchronized operation, such a time deviation, especially a delay, on one of the bus systems must be put into effect on the other bus system in order to obtain synchronism again. Accordingly, such time deviations on all the bus systems are added to one another and the fault or error is propagated.

The object of the present invention is therefore to compensate for such time deviations, especially delays, caused by faults and thereby to obtain greater long-term accuracy of the timing of the communication and the communication matrix.

The solution according to the present invention is not necessarily confined to the TTCAN, but may be extended to comparable bus systems and protocols as regards the

requirements and constraints described hereinafter. For a clearer understanding, however, the TTCAN bus is taken as the basis for the following description.

5 Summary of the Invention

The present invention presents a method and a device for exchanging data in messages between at least two stations connected via a bus system, and a corresponding bus
10 system, the messages containing the data being transmitted by the stations over the bus system and the messages being controlled over time by a first station in such a manner that the first station repeatedly transmits a reference message containing time information of the
15 first station over the bus system at at least one specifiable time interval, the time interval being subdivided as a basic cycle into time windows of specifiable length and the messages being transmitted in the time windows, in which method, when data is
20 exchanged, a pause period of variable duration is advantageously provided at the end of at least one basic cycle, by which a time change of the beginning of the basic cycle is corrected by adaptation of the duration of the pause period. It is thereby possible to handle the
25 above-described problems in the event of deviations with regard to the cycle time in one or more bus systems.

The time change in the form of a delay in the start of the basic cycle is advantageously corrected by shortening
30 the duration of at least one pause period.

In different forms of application, a pause period may be provided at the end of every basic cycle or at the end of

every 2ⁿth basic cycle or at the end of every 2ⁿ+1th basic cycle, where n is a natural number ($n \in \mathbb{N}$).

When a plurality of, that is, at least two, successive
5 basic cycles are considered, it is therefore also
possible to provide a plurality of pause periods,
appropriate to the different forms of application, so
that a time change of the beginning of at least one basic
cycle may be distributed over a plurality of, and
10 especially at least two, pause periods, and a correction
may thereby be made.

A correction value is advantageously determined for this,
which is found from a local time of a station and a cycle
15 time. The correction value is advantageously determined
from a first difference between two local times of a
station in two successive basic cycles. In addition, the
correction value is dependent on a second difference
between two cycle times of two successive basic cycles.
20 The correction value is advantageously also dependent on
a comparison value formed by the sum of the time interval
of the basic cycle and the above-mentioned second
difference, so that the correction value corresponds to
the difference between the first difference and the
25 comparison value.

It is thus advantageously possible, when at least two
pause periods are used in at least two successive basic
cycles when exchanging data, for the correction value to
30 be distributed in a specifiable manner over the at least
two pause periods, so that, if the duration of a pause
period is not sufficient to correct the time deviation,
time compensation is also possible over a plurality of

pause periods and basic cycles. In particular, in this instance the correction value may be evenly distributed over the at least two pause periods rather than being distributed in a specifiable manner.

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Further advantages and advantageous embodiments will be apparent from the description and from the features of the claims.

10 Brief Description of the Drawings

The present invention is described in detail below with reference to the Figures shown in the drawings, in which:

15 Figure 1 shows a bus system having a plurality of stations,

Figure 2 shows a system having two bus systems which are coupled to each other,

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Figure 3 shows a total cycle for exchanging data, having a plurality of basic cycles,

Figure 4 consisting of Figure 4a and Figure 4b,

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shows the effect of a fault without the pause period according to the present invention,

Figure 5 consisting of Figure 5a and Figure 5b,

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shows the correction of a fault using the pause period according to the present invention, and

Figure 6 consisting of Figure 6a and Figure 6b, shows a plurality of successive basic cycles with a correction according to the present invention being determined.

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Description of Exemplary Embodiments

TTCAN is essentially based on time-triggered periodic communication which is clocked by a timer (Figure 1, 101) using a time reference message or short reference message RN. The time interval or the period up to the next reference message RN has the duration of cycle time ZZ. Figure 1 shows a bus system 100 having a plurality of bus stations 101 to 105. Each station 101 to 105 has its own time basis 106 to 110 which on the one hand may be formed by an internal element, for example a clock, a counter, a clock generator etc. or may be transmitted to the respective station from the outside. The respective local time basis LZ1 to LZ4 is, for example, especially a counter, for example a 16-bit incremental counter, that may be influenced only by a hard reset. A local time basis is implemented here in each station 102 to 105. One specific station, the timer, in this case 101, has an exposed position. Its time basis 106 is referred to as the global time basis having the global time GZ and is either implemented in the timer 101 or transmitted thereto from the outside. The global time GZ is formed in principle in each station by the local time basis 107 to 110, or the local time LZ (LZ1 to LZ4), and an offset OS1 to OS4. That offset OSG in the timer 101 is normally 0 (OSG = 0). All the other stations form their view of the global time GZ from their local time LZ (LZ1 to LZ4) and the local offset OS1 to OS4 (and in exceptional cases

from OSG when $OSG \neq 0$, for example, when GZ is transmitted to timer 101 from the outside and the latter additionally contains its own time basis). The local offset is the difference between the local time at the instant of transmission (SOF, start of frame), of reference message RN and the global time information transmitted from the timer in or with that reference message RN. To determine specific points in time, for example to determine the offset relative to the respective local time and the global time, so-called time marks (timestamps) ZM1 to ZM4 and ZMG may be used, which may be stored in registers and from which it is possible to determine time correction quantities, for example the offset relative to the global time, or also a correction value for error handling, especially the correction value according to the present invention. A time mark is a relative point in time which establishes the relationship between the relative time and an action in the original bus (CAN controller). A time mark is represented as a register, a controller being capable of managing a plurality of time marks. A plurality of time marks may be assigned to a message.

Reference message RN is the basis for the time-triggered, periodic operation of TTCAN and arrow 112 indicates that reference message RN (111) is sent to the other stations (102 to 105). RN is clearly identified by a specific identifier and is received by all stations (in this case 102 to 105) as clocking information.

Figure 2 shows a system composed of a plurality of, and in this case two, TTCAN bus systems. 203B1 denotes therein a first bus, and 203B2 a second bus. Two stations

201 and 202 are coupled to the first bus 203B1. One station 205 is coupled to the second bus 203B2. Station 200 is connected to both buses 203B1 and 203B2 and acts as a connecting station or as a gateway computer, or as gateway station or gateway controller, which has access to both bus systems. Connection of the individual stations to the respective bus system is via an appropriate interface element, for example interface element 210B1 in the case of station 201. Station 200 is similarly connected as a gateway station via an interface element 204B1 to bus 203B1 and via an interface element 204B2 to bus 203B2. Alternatively, in contrast to providing two interface elements 204B1 and 204B2, it would be possible to provide one interface element that has two terminals for connection to bus 203B1 and to bus 203B2. Also shown in station 200 and 201 are a clock generator 211 and 206, respectively, and a timer component having an internal clock source or also a local time basis 207 and 212, respectively, especially a crystal or an oscillator, especially a VCO (voltage controlled oscillator). There is also present within the respective timer component 206 or 211 a time-recording component, especially a counter 208 or 213, respectively.

Control functions in the respective station, especially for the input/output of data on the bus system, for taking time information from the timer component, or also the calculation of the offset and the determination of the correction values for comparison of the time marks and for synchronizing the buses and bus stations, and further processes and process steps may be performed by components 209 and 214 forming processing components, especially a microcomputer or microprocessor or also a controller. Parts of those functionalities or the entire

functionality may, however, be present directly, that is, implemented, in the respective interface component. In addition to every other station, in this case the gateway station also may be specified as the timer of the global time, that is to say, as the sender of the reference message, especially for both bus systems. Essentially, therefore, the system composed of at least two bus systems shown in Figure 2 is to be regarded for each bus system in the same manner as the system having one bus system which is shown in Figure 1, it being necessary for the various bus systems to be synchronized, especially in applications where safety is critical. As a result, the errors described in the introduction propagate from one bus system to the other.

Figure 3 shows the principle of exchanging data by time-triggered, periodic transmission of messages over time. That message transmission is clocked by the timer of the respective bus system using reference message RN. By definition, basic cycle BZ may, as shown here, include the actual time windows for messages ZF1 to ZF4 and also ZFRN, the time window for the reference message, and a pause period PZ. Cycle time ZZ generally corresponds to the time for such a basic cycle.

For the sake of clarity, the time windows for data transmission ZF1 to ZF4 will be referred to hereinafter as data cycle DZ, cycle time ZZ including reference message RN in basic cycle BZ and also pause period PZ, in this case from t_0 to t_6 , t_6 to t_{12} , t_{12} to t_{18} , and t_{18} to t_{24} . This accordingly gives in the example illustrated 4 data cycles DZ0 to DZ3 similarly in 4 basic cycles BZ0 to BZ3.

As shown, from t0 to t1, t6 to t7, t12 to t13 and t18 to t19, that is to say, in time window ZFRN, reference messages RN of the respective basic cycles BZ0 to BZ3 are transmitted. The structure of the time windows ZF1 to ZF4 that follow a reference message RN, that is to say, their length in segments S, their number and their position in time, may be specified. It is thereby possible to form from a plurality of basic cycles with their associated reference messages, data cycles and pause periods a total cycle GZ which begins at t0 and ends at t24, in order to be repeated again. Time windows ZF1 to ZF4 include, for example, from two to five segments S each having, for example, 16, 32, 64, etc. bit times. The messages sent are shown circled in Figure 3 as RN and A to F. All of those messages of all the stations of at least one bus system are organized as components of a matrix that represents the total cycle GZ, the so-called communication matrix. That communication matrix is composed, therefore, of the individual cycles BZ0 to BZ3 with their associated reference message RN, corresponding data cycle DZ0 to DZ3 and associated pause period PZ. Those data cycles DZ0 to DZ3 may optionally be made up of exclusive and arbitrating components. For example, on the one hand, an entire time window, such as ZF3 here, may be specified as being arbitrating in accordance with CAN or, alternatively, only a single element of a basic cycle or data cycle, such as, for example, from t15 to t16. It is possible here for the arrangement of the messages (A to F) within basic cycles BZ and data cycles DZ to be freely specified. A time window ZFx is linked for exclusive components to a CAN message object, it also being possible for a time window to be left empty or used for arbitrating components.

According to the present invention, therefore, a communication matrix in TTCAN is composed either of basic cycles with nothing but data cycles of equal length with reference message or it may add a pause, that is, a pause period PZ, in the data traffic after one or more data cycles, which pause period (PZ) is ended, for example, by an event, such as a new reference message. In Figure 3, in one particular application a pause period PZ is provided after every data cycle, that is, in every basic cycle, in this case therefore from t5 to t6, t11 to t12, t17 to t18 and t23 to t24. According to the present invention, it is also possible, however, for such a pause period to be provided only after one data cycle or after every even number of data cycles, that is to say, 2^n where n is a natural number. Similarly, such a pause period PZ may also occur after every odd number of data cycles, that is to say, at 2^n+1 , again with n as a natural number. Accordingly, the length of a basic cycle or the duration of the cycle time ZZ is made up of the time window for the reference message ZFRN, the data cycle DZ and, as shown here in Figure 3, the pause period PZ, that is to say, of a larger fixed part and a smaller pause. This method allows adaptation of the cycle time by adaptation of pause period PZ. It is thereby possible to compensate for faults, especially delays caused by message repetitions, in particular of reference message RN, during one or more cycles. A pause that is required after a data cycle, for example a pause necessitated by the system, may additionally be obtained by lengthening that cyclic pause period PZ. For reasons of notation, pause period PZ is included in the basic cycle. Equally, however, basic cycle BZ may refer to ZFRN plus DZ and the pause period may be regarded as being added, which, however, merely corresponds to a different notation and

is just as advantageous to the concept of the present invention and cannot result in any limitation.

In Figures 4, 5 and 6 which follow, the present invention
5 will be described once more in detail.

Figure 4a shows a normal procedure with reference message RN in basic cycle BZ without the use of the mentioned pause period PZ. At time t_s , reference message RN(n)
10 begins. At time t_{E1} , RN(n) has been completely transmitted and is valid. At the end of cycle time ZZ, the next reference message RN(n+1) begins at time $ts1$, which is then valid at time t_{EN} , and the next data cycle DZ follows. If, as shown in Figure 4b, a fault occurs, a
15 re-start of that reference message RN(n) takes place at time t_{NS} . That is to say, a defective message identified by an error frame, specifically a defective reference message RN in the case of TTCAN, is repeated at that time t_{NS} , since it is not possible to do without that
20 reference message. That repeated reference message RN(n) is then valid at time t_{E2} , whereupon data cycle DZ then follows in basic cycle BZ. That repetition of the message results, however, in the affected cycle time ZZ being extended and in the corresponding basic cycle BZ being
25 shifted, in particular delayed. That is to say, at the actual start time of the next reference message RN(n+1), $ts1$, the basic cycle BZ has not yet ended and does not end until time $ts2$. That is to say, the start of the subsequent reference message RN(n+1) does not occur until
30 TS2, thereby producing a deviation, especially a delay, of $ts2-ts1$ caused by the fault, that is to say, the associated cycle time and the end of the basic cycle affected is extended by that time. Each of those errors or faults leads to a further delay in the timing, with

the result that those delays add up to an increasingly greater deviation from the nominal time. In the case of two or more TTCAN buses that are to be synchronized, as shown in Figure 2, such a delay on one of the bus systems must also be put into effect on the other bus system in order to achieve synchronism again, that is to say, the time deviations, in particular delays, are added to one another on all the bus systems, thereby propagating the error or fault. With a cycle time ZZ of, for example, 900 bit times (t_{s1}) and a transmission period for reference message RN of 55 bit times (t_{E1}), if the re-start is able to take place after 40 bit times (t_{NS}) there is accordingly such a shift or delay due to the fault of precisely 40 bit times ($t_{s2}-t_{s1}$).

In Figure 5, which consists of Figures 5a and 5b, instead of the cycle time being extended and the constant basic cycle being shifted if necessary, cycle time ZZ will be composed of a constant time component, the very data cycle DZ and reference message RN, and of a variable component, a regular pause or pause period PZ. That is to say, cycle time ZZ is divided into the fixed time in the error-free case from t_s to t_p of, for example, 850 bit times and the pause time from t_p to t_{s3} of, for example, 50 bit times, once again producing in the example, as mentioned in the case of Figure 4, the 900 bit times. Accordingly, as shown in Figure 5a, from t_s to t_{E1} once again the transmission of reference message RN takes place, and from t_{E1} to t_p the transmission of data cycle DZ which is followed by pause period PZ from t_p to t_{s3} . The total basic cycle BZ therefore includes according to the present invention reference message RN, data cycle DZ and pause period PZ, the cycle time then including a possible fault and a corresponding delay and hence being

capable of being kept constant. This means that the basic cycle according to the present invention of the TTCAN lasts from the beginning of the reference message to the end of a possible pause period PZ. It is not, however,
5 necessary for a pause period to be appended to or included in every basic cycle, that is to say, a start of the new reference message $RN(n+1)$ either occurs after the end of pause period PZ at time ts_3 , which has then been transmitted and is valid at time tE_3 , or alternatively
10 already occurs at the end of data cycle DZ if no pause period is provided in a basic cycle, so that compensation of a deviation occurs in the next basic cycle having a pause period.

15 If, as previously in Figure 4b, a fault then occurs in Figure 5b and a re-start of reference message $RN(n)$ occurs at time tNS , which reference message has been transmitted and is valid at time tE_2 , and if basic cycle BZ accordingly does not begin until tE_2 and that cycle DZ
20 then ends at time tEB , it is possible to correct this by shortening pause period PZ by $tEB - t_p = tNS - t_s$. The start of the subsequent reference message $RN(n+1)$ then occurs, as intended, at time ts_3 with a shortened pause period. Thus, overall, the time provided for basic cycle BZ and
25 the pause period is shortened. It is possible to obtain a shortened basic cycle time, as is were, by reducing the duration of the pause period, precisely to at least 0.

If the length or duration of pause period PZ is not
30 sufficient to compensate for the delay caused by repetition of the message, it is also possible for the time compensation to be distributed over several basic cycles and pause periods. That distribution may, on the one hand, be specified according to any desired

specifiable scheme: $\frac{2}{3}$ to the first pause period, $\frac{1}{3}$ to the second pause period, or $\frac{1}{4}$ to the first pause period, half to the second pause period, $\frac{1}{4}$ to the third pause period, and so on, or distribution may preferably be performed by equal distribution, that is to say equal components corresponding to the number of pause periods within total cycle GZ. That distribution also makes it possible to keep that pause period small, since that time is not available for communication over the bus and thus reduces the possible bus utilization ratio. As shown in Figure 3, the possible shortening of the cycle time is taken into consideration in the communication matrix.

If such a fault occurs in the case of a plurality of interconnected and synchronized bus systems, it is possible for the correction regarding the time cycle to be carried out also on the other bus system, that is to say, on the bus system where the fault has not occurred, which permits great flexibility in error correction. That is to say, shortening of the pause period may also take place on the bus system on which the fault has not occurred, should that be necessary, for example for safety reasons. Equally, it would be possible for the adaptation of the pause period for correction purposes to be distributed over a plurality of bus systems and hence over a plurality of basic cycles of different bus systems. Using a plurality of bus systems therefore provides a very wide variety of options for achieving synchronization by lengthening and shortening pause period PZ. A pause period also does not have to be provided in every basic cycle but may be provided, for example, at the end of every 2^n th basic cycle or at the end of every 2^n+1 th basic cycle, where n is a natural

number ($n \in N$), thereby allowing time compensation to be made only at every second (odd or even) cycle in the event of a fault.

5 Establishing of the delay caused by message repetition of the reference message by determining a correction value is illustrated in Figure 6. Figure 6a shows the course of three successive basic cycles, showing in this case fault-free operation. Shown here are the start times of
10 the respective reference messages RN1 to RN4, the times when the respective reference messages RN1 to RN3 are valid and the beginning of the respective pause period PZ1 to PZ3. Figure 6a shows fault-free operation for the exchange of data. Figure 6b substantially corresponds to
15 Figure 6a except that here a fault occurs and the correction of that error by determination of a correction value is shown. The cycle time is updated at each point in time when the reference message is valid, RNvalid. The time between the start of the defective reference
20 message, in this case R3, and the start of the successfully concluded reference message, that is, RN3 Re-start, $t_{76}-t_{66}$, is ignored and the cycle time counter is synchronized with the beginning of the successfully concluded reference message. Accordingly, the delay
25 caused by the fault cannot be seen at the cycle counter. It is possible for that circumstance to be utilized according to the present invention if the local time is considered in parallel. At any point in time in the basic cycle after the reference message has been received, both
30 cycle time ZZ and local time LZ are read. To calculate the run-time since the last measurement, the difference is found between the local time read and the measurement in the previous basic cycle. As a comparison value, the

difference between the basic cycle length and the cycle time read out in the previous basic cycle is calculated and is added to the currently read cycle time. The difference between the calculated local time difference
5 and the calculated comparison value of the cycle time gives the delay due to message repetitions of the reference messages. The respective times in the cycle time are denoted by C and the respective times in the local time by L. Thus, the difference in the local time
10 for determining the correction value in relation to the fault at t76 is given by:

$$tLn = Ln+1 - Ln \text{ or, in this case, } tL2 = L3 - L2.$$

15 The comparison value for the cycle time is given by:
 $t_{n\text{Comparison}} = (\text{length of cycle time } ZZ - C_n + C_{n+1})$ or, in this case, by

$$t_{2\text{Comparison}} = 900 \text{ bit times} - C_2 + C_3.$$

20

Thus, a correction value K of $tL2 - t_{3\text{Comparison}}$ is found. That correction value is the quantity for one-off or distributed shortening of the regular pause period PZ.